NE 2045 proposal request

# Issues & Justification

## The Need

Onsite wastewater treatment systems (OWTS) serve approximately 25% of households in the United States, corresponding to over 25 million households (Amador and Loomis, 2018), and are the technology of choice in rural and suburban areas where population density and cost preclude the use of centralized sewer collection and treatment systems. In unsewered watersheds they are the sole means of wastewater treatment, even for non-residential wastewater applications. Onsite wastewater treatment systems are an integral part of the water infrastructure throughout the country and are expected to protect ground and surface waters from inputs of carbon, nutrients, pathogens, and pharmaceutical and personal care compounds. These systems are expected to function under a wide range of environmental conditions with little intervention. Properly-functioning OWTS help protect public health without which ground and surface waters used as drinking water supplies would become contaminated with pathogens, nutrients and other compounds, making them unsuitable for human consumption (Ahmed et al., 2005; O’Reilly et al., 2007; Borchardt et al., 2011; Wallender et al., 2014).

To design OWTS that function effectively under a wide variety of conditions, and meet our performance expectations, we must have a thorough understanding of the processes on which these systems rely to treat wastewater. This is particularly challenging for OWTS, which rely on complex interactions of hydraulic, hydrologic, physical, chemical and biological processes to treat wastewater. Despite their ubiquity and importance as part of the nation’s water infrastructure, our understanding of these processes at work in OWTS lags behind that for centralized sewage treatment systems.

The systematic study of OWTS has evolved considerably over the past half century, leading to improvements in understanding of how contaminant removal takes place within components in the treatment train and the receiving soil. This has led to more effective contaminant removal from changes in system design, improved understanding of the biogeochemical processes that remove contaminants, biomimicry of natural ecological systems, improved selection of soils receiving wastewater, and better placement of systems both within the soil profile and within watersheds to maximize treatment and minimize impact. These improvements have come about, in large measure, from the efforts of scientists, engineers and outreach professionals in Land Grant and private universities across the U.S., funded by federal, state and local agencies, and through collaborations with regulators and private industry. However, few options still exist for regions with challenging soil conditions (e.g. shallow soils on steeply sloping landscapes, soils with shallow depth to a limiting layer or soils with unpredictable water movement, such as regions with high clay content or karst topography), where conventional OWTS designs are difficult to accommodate. More work is needed to identify low-cost solutions for effective decentralized wastewater treatment in rural communities with challenging soil conditions, to improve residents’ quality of life and protect human and environmental health in these regions.

In addition, several new challenges have developed in different parts of the country, such as more stringent nutrient and pathogen reduction regulations, removal of chemicals of emerging concern (CECs; such as pharmaceuticals, personal care products, nanoparticles, flame retardants, etc.) present in wastewater, and high strength commercial wastewater. In addition, a changing climate presents a continental-scale challenge to OWTS. Soil-based wastewater treatment systems are regulated, designed, and built based on assumptions about the volume of wastewater applied, the magnitude and distribution of past precipitation events, the historical range of variations in depth to water table, and soil temperature over the long-term (decades). These assumptions are no longer valid in many parts of the country because of climate change related variability in precipitation, temperature, and weather patterns.

As climate change continues to alter the temporal and spatial patterns of precipitation and temperature, we must expect attendant consequences as sea levels rise and changes in groundwater levels develop. These changes will affect treatment dynamics in OWTS, through changes in soil moisture dynamics, surface and groundwater hydrology, water use patterns and associated changes in wastewater composition and volume within soil-based treatment technologies (Mihaly, 2017). Changes in precipitation (e.g. more frequent and intense events) and long-term gradual sea level and/or groundwater table rise represent poorly understood threats to OWTS. Short-term catastrophic flooding brought on by intense storm or precipitation events may present challenges to proper OWTS function and longevity. The short-term excess water infiltrating from above during floods, and the long-term upward creeping of the water table (from sea level rise or changes in groundwater table elevation) from below the drainfield reduces the unsaturated soil required for adequate wastewater renovation. The treatment performance of different types of OWTS in response to these different types of flood events has been poorly characterized, despite the substantial risks improperly treated wastewater presents to human and environmental health.

In contrast to wet conditions in some regions, climate change may produce even drier conditions in arid regions. This is likely to produce a more concentrated wastewater as more stringent water conservation measures are used to save scarce potable water, placing a greater burden on soil treatment areas to effectively renovate wastewater. New innovative OWTS designs will need to be developed in these regions to reach treatment standards that enable wastewater reuse and recycling to save precious potable supplies and still be protective of public and environmental health.

Regulatory decision-makers that set codes and policies and other stakeholders need to understand the consequences of these changes and the options available to mitigate, adapt, and plan for climate change and its effects on OWTS. As in the past, they rely on scientists, engineers and outreach professionals to carry out the research and provide them the necessary information in an effective and timely manner.

## Importance of the Work

Scientists and engineers have developed a reasonable understanding of several of the processes that underlie the functioning of soil-based wastewater treatment over the past five decades, with work conducted recently by NE 1045 and NE 1545 members helping to provide a deeper understanding. This understanding continues to develop, as does our understanding of the challenges that climate change and its attendant consequences (e.g. flooding) poses to OWTS function and longevity. We must also gain a better understanding of how to help rural communities with challenging soil conditions to get access to cost-effective and reliable wastewater treatment to safeguard public health and environmental quality.

As a “green technology” (Lindbo, 2015), OWTS are relied upon by a large majority of rural and suburban populations to help protect public health and sensitive ecosystems. Onsite wastewater treatment systems rely on an intricate set of hydrologic, biogeochemical and physical processes to renovate wastewater. These are controlled, directly and indirectly, by soil type, precipitation, temperature, and depth to groundwater. Climate change will affect the treatment capacity of OWTS as a result of changes in precipitation patterns as well as soil moisture dynamics and depth to saturation, during both short and long-term fluctuations in water table levels, compounded by the effects of sea level rise in coastal areas. Major and minor flooding events are occurring both in inland (e.g. Mississippi River and tributaries watersheds) and in coastal regions with increasing frequency, with potentially serious consequences for OWTS function during and after these events. Although these factors are likely to vary in magnitude geographically, climate change is expected to affect most areas of the nation, making the proposed research efforts applicable to a large proportion of the US population.

We are already familiar with the effects of failed or poorly functioning OWTS from previous experiences, contamination of ground and surface waters with human pathogens leading to the spread of enteric diseases (McKenna et al., 2017), as well as increased inputs of N and P to aquatic ecosystems (Chen, 1988; Fisher et al., 2016; Lapointe et al., 2017), resulting in eutrophication, anoxia and ecosystem collapse. In most cases, incidents of malfunctioning OWTS have had a modest impact on public health and ecosystem functioning, because they are generally limited in geographic scope to a relatively few systems. As climate change affects larger populations at regional and continental scales, the number of malfunctioning systems, and the magnitude of their impact, is expected to be more widespread in scope, affecting a much larger portion of the population, as well as regional aquifers and surface drinking water systems. Ecosystem effects are expected to linger for decades, particularly for nutrients like P, for which removal pathways are physical, and for N, which relies on microbial processes, with severe constraints, for removal from ecosystems.

Traditional OWTS designs that rely on deeply placed soil treatment areas are unsuitable in certain landscapes, including near-shore coastal regions with shallow water tables (e.g. the eastern seaboard of the US) or low relief coastal plain areas with shallow water tables, soils with shallow bedrock, as well as in regions where soil parent material, depth, texture and structure prevent water from moving through the soil in a timely manner (e.g. the Piedmont regions of North Carolina and Georgia in the US). Some economically disadvantaged regions of the US still lack adequate onsite wastewater treatment systems (e.g. Appalachia (Hughes et al., 2005; Cook et al., 2015; Arcipowski et al., 2017)), resulting in the rise of preventable enteric diseases (e.g. rural Alabama (McKenna et al., 2017)). Rural areas with challenging soil conditions would benefit from cost-effective innovative ecological wastewater treatment designs that mimic natural systems, maximize wastewater treatment, and protect public and environmental health.

In Coastal areas of the United States there are various additional changes to soil systems as mean sea level is projected to rise at an accelerated rate through time and greater than 30 cm by 2100 (Pierfelice et al., 2017). Rises in mean sea level coupled with increased drought will likely allow for extensive saltwater intrusion from the ocean up estuaries and into current upland areas. Changes in soil salinity alter fundamental soil biogeochemical processes, which will in turn impact the functionality of OWTS. For example, salinity is harsh on many terrestrial microorganisms and biogeochemical treatment of wastewater effluent may slow as more salt-tolerant organisms replace less tolerant ones (Pierfelice, 2013). Cycling of nutrients will likely change due to saltwater stress and reduction of porewater sulfate into sulfides will likely become an alternate pathway for anaerobic microbial respiration. Research in coastal soils undergoing salinization has shown greater P mineralization and turnover, short-term desorption of exchangeable ammonium, and reduction in long-term net nitrification rates (Noe et al., 2013). Thus, OWTS in coastal areas are the most likely systems to be adversely impacted by climate change and sea level rise in the next 100 years.

Because drinking water sources for large urban areas are often found in rural landscapes where OWTS are common, the impact will not be limited to rural areas alone. This is particularly true with respect to increased inputs of organic C and nutrients to surface and groundwater reservoirs from OWTS which can interfere with water disinfection processes and result in the production of trihalomethanes, known human carcinogens. In addition, as CECs become pervasive in drinking water resources, more research is needed to determine what soil conditions within the soil treatment area help remove these contaminants and help mitigate their impacts.

## The Technical Feasibility of the Research

The proposed research is technically feasible. The tools and techniques necessary to carry out the research have been developed, and include traditional water quality measurements (e.g. 5-day Biochemical Oxygen Demand (BOD5), coliform enumeration, nitrogen and phosphorus concentrations), and measurements of hydropedological properties of soils, which can be combined with cutting-edge approaches from a variety of science and engineering fields to understand and model the fate of contaminants from wastewater. Combining traditional approaches to assessing water quality and soil properties with 21st century techniques, such as advanced computer modeling of hydrological and biogeochemical processes, identifying nutrient transformations, and applying molecular genetic tools to identify the microorganisms responsible for both water quality degradation and improvement can lead to important insights and implications for improving wastewater treatment. The research efforts of biological and environmental engineers, pedologists, hydrologists, soil physicists, soil microbiologist, computer modelers, environmental and public health scientists, and extension and outreach professionals at state and private universities have led to a better understanding of the challenges presented by climate change and the potential solutions.

## Advantages for Doing the Work as a Multistate Effort

Addressing the research and outreach challenges presented by a changing climate requires the expertise of a broad spectrum of scientists, engineers and outreach professionals. Developing novel cost-effective approaches to wastewater treatment in areas with challenging soil conditions also necessitates collaboration among these researchers and outreach personnel from several different disciplines. The necessary breadth of expertise and perspectives is already found in select Land Grant and private universities across the US. Researchers are currently working on various aspects of the science and engineering of OWTS and the wastewater-related challenges many communities face today. Collaboration among professionals with different areas of expertise leads to better insights, experimental designs, analyses and overall better outcomes. In some instances, the results of this research are broadly applicable, as is the case with studies focusing on fundamental processes. In other instances, the research focuses on addressing problems that are local or regional in nature as a result of unique geological, geographical or regulatory issues (e.g. coastal zones subject to sea level rise or areas with challenging soil conditions). Similarly, outreach professionals develop materials that are tailored to national, regional and local issues, depending on the circumstances. In order to carry out and disseminate research that is responsive to the broad range of problems and constituencies in the US, the proposed work needs to be a comprehensive and collaborative effort done at a multistate level.

## The Likely Impacts from Successfully Completing the Work

We anticipate that completion of the proposed work will lead to evidence-based solutions to OWTS problems associated with ecological design of OWTS that addresses the challenges of climate change and challenging soil conditions. Specifically, we expect that results from examination of fundamental physical, chemical and biological processes – and their response to changes in hydrologic regime – will, in combination with studies focusing on local and regional aspects of OWTS function and design, provide solutions to the challenges of wastewater treatment in light of a changing climate and regional soil constraints at appropriate spatial and temporal scales. Communities served by OWTS across the US and abroad impacted by flooding will benefit from the proposed research efforts to understand the impacts to OWTS during and after flood events – from both short-term precipitation-induced floods and chronic changes in sea level and groundwater tables. Developing innovative, cost-effective wastewater treatment options for areas with challenging soils will improve the quality of life of rural residents by protecting public health, as well as the health of water resources in their communities and farther downstream. Understanding the removal mechanisms for CECs in STAs located in different soil types and landscape positions will help local, state, and national decision makers make informed policy and regulation revisions to protect at risk water resources. This will be come even more important as the areas become more impacted by climate change and sea level rise. Furthermore, we will share these solutions among OWTS outreach professionals and make them available to clientele and stakeholders so that policy and management decisions can be developed to optimize the use of decentralized wastewater treatment to remediate or avert large-scale public health and ecosystem crises.

# Related, Current and Previous Work

### University of Georgia (UGA)

**Impact of septic systems on water quality of streams in urban watersheds.** NE 1545 researchers at the University of GA investigated the impact of septic systems on water quality of streams in watersheds of metropolitan Atlanta using targeted monitoring of fecal indicator bacteria and microbial source tracking markers as well as watershed scale modeling with the Soil and Water Assessment Tool (SWAT). Twenty-four urbanizing watersheds impacted by a gradient of septic system density and land use characteristics were monitored for three years. Results indicated that density of septic systems and the proximity of septic systems to streams were significant drivers of fecal pollution in the watersheds(Sowah et al., 2017). Moreover, the influence of septic systems was seasonally dependent. SWAT model results pointed to septic system influence as a result of their proximity to local streams(Oliver et al., 2014). Septic system water use was also estimated to be about 6% consumptive, contrary to common assumption that it was 100% by planning agencies in Georgia (Hoghooghi et al., 2016). Educational materials on septic systems were developed and shared with metro Atlanta residents through UGA extension networks and publications(Bauske et al., 2017). A survey of residents indicated that they were willing to pay more for water quality improvements when the improvement is explicitly quantified.

### University of Kentucky

**Spatial distribution of depth to restrictive horizons.** Restrictive horizons are found throughout the Northeastern, Southeastern, and North Central United States. Fragipans are a common restrictive horizon that cover approximately 1 million km2 of the United States. These horizons pose significant issues for the adequate operation of OWTS as they limit the volume of soil material available for wastewater treatment. We still do not fully understand the processes that generate fragipan horizons, which limits our ability to predict the depth of fragipans horizons across landscapes. Researchers at the University of Kentucky are working to understand the processes that generate fragipans in Western Kentucky. Eight soil profiles have been sampled in western KY. They are currently working to better define fragipan characteristics, such as prism size, brittleness, and bulk density. Using available LiDAR-derived digital elevation models, GIS applications, and sampled soil profiles along with available soil databases (e.g. NRCS National Cooperative Soil Survey Soil Characterization Database), they will build spatial relationship to predict depth to restrictive horizons. This preliminary work will be used to better inform the evaluation of sites for OWTS in Kentucky, and will be used for future investigations into the impact of fragipans on OWTS operation.

### Michigan State University (MSU)

**Land application of commercial wastewater.** Land treatment of food processing wastewater can irrigate a crop, provide nutrients, recharge aquifers, reduce energy use, reduce greenhouse gas emissions, and save resources. However, when excessive carbon is land applied, the soil becomes anaerobic and several metals become mobile when reduced. Although aerobic conditions prevent metal mobilization, denitrification is inhibited under this condition. Critical for land application is pretreatment and strategic organic and hydraulic loadings to maximize efficient waste management and minimize environmental impacts. A long-term field study examined direct soil oxygen and moisture monitoring using remote sensors to ensure aerobic conditions. Finite element modeling using Hydrus Constructed Wetland 2D was conducted and demonstrates the potential to simulate land application of wastewater under numerous scenarios. Calibration and verification studies are ongoing. The outcome is a change in action and condition in that careful operations and design allow food processors to continue using land application.

**Pretreatment of winery wastewater.** Many Michigan wineries use land application for wastewater management, but new regulatory recommendations require more land so a compact alternative is desirable to prevent the loss of vineyard space to wastewater treatment area. To reduce treatment area, gravel bed vertical flow constructed wetlands (GBVFCWs) were studied to remove high concentrations of BOD and nitrogen from winery wastewater. The GBVFCWs consist of three subsurface gravel cells connected in series that utilize aerobic and anoxic conditions to promote biological degradation. A bench-scale GBVFCW was constructed and operated. At 68°F and at various loading frequencies, the GBVFCW removed an average of 99% COD, 62% nitrate, 94% total nitrogen, and ammonia to levels below detection limits. Nearly all treatment occurred within the first cell, indicating that aerobic and anoxic environments were present within the cell. A HYDRUS Constructed Wetland 2D model is being evaluated for its potential use in this application. Based on this research, GBVFCWs are a compact and effective option for winery wastewater treatment. Additionally, onsite application of wastewater, as compared to treatment in a traditional activated sludge processes, reduces greenhouse gas emissions. Reductions are achieved by not using energy for wastewater aeration, carbon dioxide uptake by the plants grown when using the wastewater, and reduced production of industrial nutrients for the crops.

### University of Minnesota (UMN)

**Groundwater table dynamics below drainfields.** Working with MnDOT, UMN researchers are evaluating water tables and groundwater mounding at 25 existing septic systems, using automated water level recorders between early April through mid-November. This data is being used to evaluate what level of vertical separation to a periodically saturated condition is maintained at each of these sites; and whether the groundwater below these systems rises either during high wastewater discharge times or wet climatic periods.

**Chemicals of emerging concern.** Chemicals of emerging concern (CEC) have been sampled at four highway safety rest areas and a land application site to determine design parameters affecting treatment. Samples were collected prior to soil treatment, in the soil itself beneath the systems and in monitoring wells and evaluated for CECs. The water samples were also analyzed for general wastewater contaminants. Year one of this study has been completed, and work will continue for 3 more years.

**Microbial community dynamics in drainfields.** The soil treatment areas (STA) from one highway rest area was sampled and analyzed to determine the soil microbial populations (metagenomics) using next generation (DNA) sequencing. The goal is to compare STA microbiology, natural soil microbiology after the system has been in operation for one year, and then at year two after pretreatment is added.

**Watershed-scale chloride input assessment.** High chloride levels in surface waters and groundwater are an emerging concern in Minnesota, as they can negatively impact aquatic and plant life. Work continues to evaluate at the watershed scale the chloride sources and potential reduction from different sources.

### North Carolina State University (NCSU)

**Understanding spatial relationships among existing onsite systems, soil types, and coastal zone flooding.** Millions of people live in coastal regions of the eastern United States, and many of them rely on on-site wastewater treatment systems to effectively treat wastewater and protect water quality. The functionality of on-site systems can be adversely affected by predicted coastal climate change via increased flooding, salinization of soils, and rising ground water tables. NCSU faculty have ongoing research to quantify the location of existing coastal on-site systems in North Carolina and allow for prediction of climate change impacts to these systems. Researchers at NCSU have identified 17 possible counties to work with that have available GIS data for research analyses. These counties have a combined total estimated 2017 population of 901,843. Necessary GIS data for advanced geospatial analyses (including available ground water table heights, salinity data, soil survey units, county parcels, LiDAR, etc.) have been gathered. GIS analyses to correlate risk of flooding, salinization, and ground water rise to existing georeferenced on-site system locations has begun in a subset of coastal counties (n = 7) and are expected to conclude within the next year. These preliminary findings will be used to direct future targeted investigations of coastal soil types and counties most at risk of experiencing adverse effects in the functionality of OWTS due to sea level rise.

### Ohio State University (OSU)

**Reuse of reclaimed wastewater through onsite spray irrigation.** Research on winter reuse of reclaimed wastewater was conducted in Ohio. Issues evaluated were impact on plants, equipment protection, pathogen control, and pollutant runoff potential from cold soil. A new wastewater irrigation demonstration system was installed for a farm house on an Ohio Farm Bureau demonstration farm in the western Lake Erie watershed. The onsite spray system replaces direct discharge of septic tank effluent from the century old farmhouse.

**Treatment of high salt content wastewater.** Salt levels in wastewater become an issue from food processors that use salt for curing or pickling. With fresh water scarcity, the use of high salt-content water for toilet flushing is also an option. Research is looking at the impact of salt on wastewater treatment using sand bioreactors. In addition, research on using reverse osmosis to remove salt and nutrients from treated food processing wastewater was conducted. The overall objective was to analyze the effectiveness of nutrient removal from wastewater effluent by membranes. The focus was on analyzing the relationship comparing wastewater strength with membrane fouling rates and pollutant removal efficiencies. A lab-scale reverse osmosis system was set up with pressure capabilities of up to 1000 psi. Membranes tested at 800 psi had greater and more consistent removal rates. The most efficient membrane shows removals in all categories of at least 85%.

### University of Rhode Island (URI)

**Assessment of Non-proprietary Passive Nitrogen Removal Septic Systems.** In collaboration with partners in Massachusetts (MASSTC), researchers at URI are conducting experiments to test the nitrogen removal potential of layered soil treatment areas (STA). These leaching systems facilitate sequential nitrification (in a sand layer) and denitrification (in a sand layer mixed with sawdust) as septic tank effluent percolates through to groundwater. Three experimental residential layered systems are being assessed for (a) N removal (b) microorganisms involved in N transformations, and (c) greenhouse gas emissions. All STA were constructed with a control (conventional) STA beside them filled only with sand and receiving the same wastewater, which allowed comparisons with a STA like those currently installed in Massachusetts.Analysis of the final effluent nitrogen removing performance data indicates that the layered STA meet state N regulations in 80% of samples collected, compared to 20% of control samples. No significant differences were observed between greenhouse gas emissions from the layered and control STAs. Research assessing the microbial community’s involvement in N-cycling is ongoing.

**Assessment of advanced nitrogen-removal onsite wastewater treatment systems in Charlestown, RI.** Advanced N-removal OWTS are designed to facilitate nitrification and denitrification of wastewater before final effluent is applied to the soil treatment area and percolates to the groundwater. In this study, URI researchers selected 48 advanced N-removal OWTS in the town of Charlestown, Rhode Island to determine the capacity of 6 different N-removal OWTS technologies to meet the RI Dept. of Environmental Management’s standard for final effluent total N (TN) concentration of 19 mg/L or less and to determine if seasonally-used systems require any microbial “ramp-up” time before they are capable of N removal. The year-round systems were sampled quarterly, and the seasonal systems were sampled four times (monthly) over the summer (June through September) occupancy period.

Findings indicate that home occupancy pattern does not influence TN concentrations in the final effluent. Contrary to the initial hypothesis, there does not appear to be any sort of microbial ramp-up time. However, technology type does significantly influence effluent ammonium and TN concentrations; but it does not influence nitrate concentrations. One of the investigated technologies appears to not be nitrifying sufficiently, thus limiting it’s TN removal efficiency. The proportion of systems showing final effluent median TN values less than RIDEM’s standard of 19 mg/L varies by technology type.

**Using IRIS tubes as an indicator of denitrification.** Advanced onsite wastewater treatment systems (OWTS) and soil treatment areas are used to remove nitrogen from wastewater. These systems rely on sequential nitrification and denitrification to remove nitrogen in gaseous forms: N2 and N2O. Determining the extent to which denitrification takes place in these systems is a complex, time-consuming task. Manganese oxide reduction takes place at a redox value close to that for denitrification. URI researchers gathered preliminary data on the use of IRIS (indicator of reduction in soil) tubes coated with manganese oxide to assess the redox conditions in an advanced N-removal OWTS. They found that loss of color – indicative of Mn reduction – from the IRIS tubes took place in the anoxic and hypoxic compartments of the system after in situ incubation for 7 days, whereas no loss of color was observed in oxic compartments. Laboratory experiments show that loss of color from IRIS tubes submerged in anoxic wastewater was evident after 30 min. These results suggest that IRIS tubes coated with manganese oxide paint may be a quick, inexpensive indicator of redox conditions that support denitrification, thus helping system maintenance providers assess conditions appropriate for denitrification.

**Impact of soil water-filled pore space on greenhouse gas emissions.** Microbial removal of C and N in soil-based wastewater treatment involves emission of CO2, CH4, N2O, and N2 to the atmosphere. Water-filled pore space (WFPS) can exert an important control on microbial production and consumption of these gases. Researchers examined the impact of WFPS on emissions of CO2, CH4, N2O, and N2 in soil microcosms receiving septic tank effluent (STE) or effluent from a single-pass sand filter (SFE), with deionized-distilled (DW) water as a control.

Emissions of GHG from soil were not constrained by the lack of organic C availability in SFE, or by the absence of NO3 availability in STE, and addition of acetate or NO3 resulted in lower emissions in a number of instances. Emission of 15N2 and 15N2O from 15NH4 took place within an hour of contact with soil, and production of 15N2 was much higher than 15N2O. 15N2 emissions were greatest at the lowest WFPS value and diminished markedly as WFPS increased, regardless of water type and soil texture. Our results suggest that the fluxes of CO2, CH4, N2O, and N2 respond differently to WFPS, depending on water type and soil texture.

**Groundwater tables in near-shore areas compromising separation distance for majority of coastal septic systems.** URI researchers investigated how groundwater table dynamics along the southern RI coast impact septic system drainfield separation distance (the distance from the drainfield’s infiltrative surface to the groundwater table) in near-shore areas. Historical data suggest that overall, groundwater tables are rising at a rate of 14mm/year along the southern RI shore, though the rates are greater in communities importing potable water. Using long-term groundwater monitoring wells, coupled with ground-penetrating radar surveys of 10 different drainfields, they determined that 20% had adequate separation distance throughout the year, while 50% had inadequate separation distance at least some of the time, and 30% never had adequate separation distance. At one site, during a small coastal storm event, the water table reached the infiltrative surface of the drainfield. Next steps are to share this information with regulatory agencies to inform a discussion on improving the regulation-specified method of groundwater table elevation determination, as current methods are not accurate in near-shore areas. The methods used for these analyses could be applied to many coastal communities in the US and abroad, and present an important consideration for the sustainability of coastal communities and their adaptation to climate change.

**Modeling the effects of storm damage to near-shore septic systems along southern RI coast.** Researchers at URI have created a model using existing flood maps for different storm recurrence interval probabilities and mean parcel elevation to predict which septic systems would be affected/damaged to varying extents along the southern RI coast should a storm affect the area. Septic systems were predicted to face serious impacts (extensive repairs / complete replacement required in the aftermath of a storm event), moderate impacts (minor repairs required to restore full system functionality) or ephemeral impacts (no lasting impacts once storm waters recede), based on proximity to the Atlantic Ocean and mean parcel elevation. Repairs could cost anywhere between $1K to over $30K per system, depending on the nature of the damage. The model was validated using damage descriptions of system damage sustained during Hurricane Sandy in 2012 in Charlestown and Westerly, RI. The model predicts damage to systems with ~70% accuracy, underestimating damage on up to 20% of systems. The model could be improved by incorporating more parameters and details, including actual system elevation, surrounding microtopography, system type and better damage descriptions in the aftermath of storms. Current coastal community resiliency plans are not adequately addressing the threat posed by storms with respect to OWTS, which could result in significant environmental degradation and public health risks. The methods applied in these analyses could be adapted to many coastal communities in the US and abroad and present an important consideration for the sustainability of coastal communities and their adaptation to climate change.

Combined efforts of the NE1545 team

Education and outreach has always been a strong emphasis of the NE 1045 and NE1545 project technical committee, and in 2019 alone there were over 6,700 direct contacts made during nearly 200 workshops and classes, enabling over 1,850 OWTS practitioners to receive continuing education credits in order to renew their professional licenses, and helping nearly 520 new professionals to receive OWTS design training. About 335 professionals were directly reached in presentations specifically addressing climate change and OWTS. In addition, members of NE1545 delivered trainings and created materials to help homeowners understand how to maintain and prolong their septic systems’ functional lives. We expect these numbers to increase as we continue to prioritize this commitment to education and outreach in our new proposal, and members begin to explore and implement online continuing education content and courses.

# Objectives

1. Improve our understanding of the interactions among wastewater, soils, biogeochemical cycles and processes and treatment performance (contaminant removal) of existing and novel wastewater treatment technologies in different geographic regions and landscapes over time and considering climate change.
2. Examine watershed-level impacts of septic systems on water quality and other environmental parameters in suburban, rural and coastal areas.
3. Develop educational materials and tools to acquaint the public and practitioners about management, operation, maintenance and health issues related to OWTS in light of system performance, and the need for adaptation to climate change.

## Methods

The two main functions of the STA are (i) to allow for infiltration of wastewater in the subsurface, and (ii) to remove contaminants from wastewater. The main objective of the proposed work is to further our understanding about how soil characteristics, system design, microbial community dynamics, and climate change affect the hydrologic and biogeochemical processes that govern the functioning of the STA. This will be based on data gathered from experimental, observational and modeling efforts at a variety of spatial (microcosm to watershed) and temporal (hours to decades) scales from different geographic regions and landscapes in the US.

We recognize that hydrologic and biogeochemical processes do not take place in isolation from each other, but often interact in ways that can enhance or interfere with the functioning of OWTS. For example, removal of dissolved and particulate organic C by microorganisms in the STA can reduce the development of a biomat – a low-permeability layer of organic polymers, microorganisms and inert particles that forms at the STA-native soil interface that restricts the infiltration of wastewater and can result in hydraulic failure. In coarse-textured soils or soils with well-developed structure, the development of a biomat may be beneficial in removal of pathogenic organisms due to increasing hydraulic retention time needed for effective removal processes to occur. On the other hand, the effectiveness of bacteria and virus removal in the STA is affected by soil type and is sensitive to water saturation in the soil, with less removal observed as the soil moisture content increases. The combination of biomat formation, soil permeability, and soil moisture content (wastewater loading rate, rainfall infiltration, and water table dependent) all must produce the “Goldilocks” point where both soil water movement and effective wastewater treatment are optimized. Thus, the proposed work will address these interactions within the context of both regional differences in soil type and climate.

We are also aware of the practical limitations presented by short-term experimental and observational studies in terms of predicting climate impacts on STA functions, particularly with respect to long-term effects of climate variables. To this end, we will include a modeling component that incorporates climate variability and change in their influences on hydrologic and biogeochemical processes in the STA.

Effective wastewater treatment in regions with suboptimal soil types require not only that we understand how existing systems work and interact with soil type and climate, but also how these may be modified or replaced to improve their effectiveness, to provide innovative and cost-effective solutions in regions with challenging soils, as well as adaptation to new climate regimes. To this end, the proposed research will be conducted on both natural and engineered soils and treatment media, and on conventional and innovative STAs.

Specific methods by objective:

*Objective 1. Improve our understanding of the interactions among wastewater, soils, biogeochemical cycles and processes and treatment performance (contaminant removal) of existing and novel wastewater treatment technologies in different geographic regions and landscapes over time and considering climate variability.*

We will examine relationships among soil properties, system design, climate variables and movement of water in the STA and underlying vadose zone, with attention to the following scenarios:

1. Impact of (i) increased water inputs to surface soils and (ii) reduced wastewater inputs to the STA on (i) vadose zone hydraulic processes and (ii) surface and subsurface transport of contaminants.

2. Impact of rising water tables on water movement at the individual system and watershed scales.

3. Interactions among changes in water inputs, depth to water table and rising temperature in the context of water movement and contaminant transport.

4. Changes in system performance over time as systems become established after installation and begin to age and eventually approach the end of their design lives.

Work will be conducted at scales from the individual STA to the watershed, and will include observational and experimental studies, as well as laboratory and field-scale studies. We will employ sampling schemes that capture spatial and temporal variability at scales relevant to the processes under study.

We will measure response of hydrologic variables to precipitation and temperature changes of differing magnitudes in different soil types and regions of the country. When possible, we will make measurements in existing conventional and innovative STAs receiving residential strength wastewater. We will use intact core mesocosms (cm-m scale) to develop detailed understanding of hydraulic processes.

We will also examine established drainfields for long-term performance, determine their actual hydraulic loading rate (which is generally lower than the design loading rate) and investigate the hydraulic function of systems of different ages. Samples of drainfield components can be evaluated in a lab setting for performance and function. Soil pore water and groundwater at different depths below the drainfield can be evaluated for contaminants to assess performance in the field. Evaluating soils in established, aging drainfields for hydraulic conductivity will also yield insights into soil treatment mechanisms.

The information gathered will be used to develop conceptual and quantitative models of the relationship among soil properties, climate and water movement and their impact on hydraulic function of STAs and site suitability. In addition, our results will be used in combination with data from efforts described above to modify existing models to predict impact on hydrology as well as transport of pollutants. Our results will be used to develop outreach materials for decision makers relative to siting, design, and regulation of OWTS (Objective 3).

We will focus our efforts on the biogeochemical and physical processes that result in (i) the removal/retention of dissolved contaminants, including organic C, N, P metals, and contaminants of emerging concern, including medications and personal care products, and (ii) removal/inactivation of pathogenic viruses and bacteria. These are the main contaminants of concern across the country associated with OWTS contamination of ground and surface waters. Experimental and observational studies will be conducted at scales from microcosm to field.

One major obstacle to OWTS research in rural areas of the US is that many counties currently lack detailed information on the geospatial location and functionality of existing systems. Lack of available geospatial information is a major limitation to any large-scale initiative to understand the impacts of climate change, flooding, and sea level rise on OWTS. For example, ongoing research in North Carolina has shown that there are 17 coastal counties expected to undergo major environmental changes due to projected sea level rise over the next century. Of these counties, only 7 have available geospatial information (GIS shape files, georeferenced CAD files) with the location of existing structures and OWTS. The remaining 10 rural counties rely on paper copies of permit plans and locations that, in many cases, have not been validated in several decades (M.C. Ricker, personal communications). As such, we need to work with counties and municipalities to generate digital OWTS information for use in future coastal research initiatives.

We will also further our understanding of which biogeochemical processes contribute to removal/retention of dissolved contaminants using a variety of approaches, including:

1. Measurements of the concentration of contaminants in water inputs and outputs and as they move through the STA and their response to soil type and climate change. This will allow us to determine whole-system removal rates and examine the role of soil depth and associated changes in soil physical and chemical properties.

2. Determination of variables thought to control the removal/retention of contaminants in the STA and their response to soil type, system design and climate change. These include changes in the concentration of (i) dissolved electron donors and acceptors, (ii) dissolved and gaseous reactants and products from redox reactions, (iii) redox potential, and (iv) pH. We will also determine soil properties (e.g. organic C, mineralogy, cation exchange capacity, buffering capacity). This information will help us identify the biogeochemical pathways by which contaminants are removed/retained, and the variables that control these processes.

3. Determination of the structure and function of microbial communities and groups of microorganisms in treatment processes and their responses to environmental challenges. This information will be used to test hypotheses on the microbial communities that carry out removal/retention of contaminants and their relationship to system variables. Emphasis will be placed on molecular genetics methods to analyze community structure and function, including metagenomic analysis of bacteria, archaea and fungi.

4. Developing mechanistic descriptions of biogeochemical removal/retention processes using analysis of stable isotopes (e.g. 13C-drugs, 15N-NH4, 34S-SO4) (enriched and natural abundance) in contaminants compounds and potential intermediates to track specific transformations.

5. Create relative risk maps using GIS models of predicted flooding in response to changes in precipitation and sea level rise. Compile and map OWTS locations with existing soil types in flood-prone areas, including coastal zones to better evaluate the spatial impacts of specific biogeochemical changes driven by increased flooding and soil salinization.

Together, the information gathered in this objective will provide us with a more accurate picture of the biogeochemical processes that remove/retain dissolved contaminants from wastewater in the STA. These data will be useful for the development and testing of models predicting the impact of soil type and climate change on fate and transport of dissolved contaminants. It will also help us address the challenges posed by problematic soils and climate change through manipulation and/or modification of system variables in existing systems, and engineering and design of future systems to optimize water quality functions in the context of changing climate variables.

*Objective 2. Examine watershed-level impacts of septic systems on water quality and other environmental parameters in suburban, rural, and coastal areas.*

Both simulation models and monitoring methods will be used to accomplish our objectives. Results of modeling efforts will be used to inform decisions on system siting and design.

Using simulation models, we will optimize the OWTS design by adjusting the design parameters and looking at the model output in terms of discharge capacity, chemical discharge, and pathogen fate. Once we have identified one or two optimal design criteria through simulation, we will test those designs in field-based pilot studies and collect data to show the workability of the new design criteria.

Monitoring efforts will include:

1. Identification of septic systems’ impact on fecal contamination of suburban and rural streams, by monitoring multiple small (first-order) streams. Some of the stream watersheds will be entirely reliant on septic systems for wastewater dispersal and others will be forested (control) watersheds. We will sample each stream under base flow conditions monthly (*synoptic sampling*). We will also use *targeted sampling* at multiple locations along streams with high bacteria or viral counts to identify potential sources including failing septic systems. Streambed sediment samples, in addition to water samples will be collected. Synoptic samples will be collected monthly to capture the seasonal flow variations (winter, fall, spring, and summer) under baseflow conditions. We will combine targeted sampling with a procedure to identify failing septic systems. To screen for failing septic systems that contribute bacteria to streams, we will use GIS databases containing the location, age, and type of septic systems in different communities. We can then conduct site visits to look for physical evidence of failure.

*Objective 3. Develop educational materials and tools to acquaint the public and practitioners about management, operation, maintenance and health issues related to OWTS in light of system performance, and the need for adaptation to climate change.*

Utilizing research knowledge gained from project Objectives 1 and 2, we will synthesize data, develop, and deliver stakeholder-appropriate education and outreach materials related to soil type and/or climate change and: (i) interactions of soils, water, and wastewater relative to soil and site suitability for OWTS; (ii) wastewater biogeochemistry in advanced treatment OWTS, in soil treatment areas and underlying soils; and, (iii) modeling of wastewater movement and contaminant migration in soils underlying OWTS soil treatment areas.

To help OWTS practitioners, we will continue the outreach work started under NE 1045 and NE 1545 by:

• Utilizing a technology matrix table that helps public and private decision makers to determine what OWTS technologies are best suited for nutrient and pathogen sensitive watersheds and addresses various on-lot site constraints such as shallow groundwater tables, shallow bedrock, slowly and rapidly permeable soils and size restricted lots.

• Working with industry and regulatory stakeholders to develop and improve materials for design, operation, maintenance, installation, economics, planning, management, and analyzing and diagnosing malfunctions of conventional and advanced OWTS as it relates to adaptation to and mitigation site constraints and of climate change.

Enhancing existing and developing new training modules for regulatory agencies to inform them of the latest research findings to help influence their policy, regulations, and decision-making capabilities.

Using the education materials described above, we propose to train OWTS practitioners, decision makers and the public. Delivery of materials will be at outreach workshops conducted within the existing network of Land Grant and private institution OWTS training centers and programs across the United States. In addition, training materials will also be delivered at state, regional and national professional conferences and trade shows. Delivery methods may include lectures, online content, distance learning venues and hands-on field exercises, fact sheets, demonstration systems and props, Power Point slides, videos and DVDs.

# Measurement of Progress and Results

## Outputs

* Refereed journal articles and publications for industry/ professional association conference proceedings related to OWTS and climate variability and climate change.
* Training workshops and associated educational materials to transfer emerging information to onsite wastewater practitioners at state, regional and national venues.

## Outcomes or Projected Impacts

* Increased interaction, knowledge, and understanding among the members of the project technical committee, the OWTS industry and wastewater practitioners concerning siting, design, installation, operation and maintenance of conventional and advanced OWTS that meet the growing challenges posed by climate change, and the need to protect human and environmental health.
* Improved or newly developed outreach demonstration education tools to help us communicate our research findings to our professional onsite wastewater practitioner communities.
* Increase in knowledge of onsite wastewater stakeholders as a result of information developed from this project being delivered through outreach education and demonstration venues.
* Increased use of advanced treatment technologies to help mitigate climate change impacts.
* Increased use of ecologically designed and installed OWTS that blend with existing and expected changes in features in the natural and built environment.

## Milestones

(2020): Distribute sponsored proposal to colleagues engaged in onsite wastewater research to raise awareness and to solicit participation. Develop and continue research efforts and strengthen multi-state research and outreach efforts. Convene the first project meeting. The purpose of this meeting will be to confirm leadership roles, assign duties to committee members to be completed during the tenure of the project and identify other scientists who may be interested in joining the project. Report on progress, expand development of methods to address objectives and development of outreach training materials.

(2021): Review progress made at the participating institutions under the different objectives, present committee reports, share and discuss common research interests and findings, and report on outreach efforts by members. Assess progress made to-date.

(2022): Present and discuss progress made in meeting project objectives. Review, identify, improve, and augment ongoing research methods based upon peer review, and by utilizing evaluations, stakeholder feedback and comments, and experiences gained from training events. Develop, improve and enhance outreach education materials, deliver them at forums and assess the effectiveness of training efforts.

(2023): Review and assess progress made on research. Collect information to assess the numbers of practitioners being exposed to new research findings at training forums. Assess to what extent the practitioners being trained are utilizing the research-based outreach training they have received to change their behaviors, or to effect change in their practices.

(2024): Present and discuss progress made in meeting project objectives. Identify, improve and augment ongoing research based upon peer review and by utilizing evaluations, stakeholder feedback and comments, and experiences gained from training events. Develop, improve and enhance outreach education materials, deliver them at forums and assess the effectiveness of training efforts. Assess interest in continuing the multi-state project efforts and writing a new project proposal.

(2025): Convene the final project meeting to discuss and evaluate prioritized research efforts, effectiveness of associated outreach forums. Present all completed standards of practice, developed publications, and final committee reports.

# Outreach Plan

The results of this proposed multistate project will be published as project reports on the project web site, as peer-reviewed publications, presentations at scientific meetings, presentations at industry conferences and decision maker meetings, and publications in industry journals, magazines and newsletters. These efforts will be done both in-person as well as online training sessions. Our project will sponsor a 2022 onsite wastewater symposium which will feature research findings from our new project. In addition, summaries of the completed work will be posted on participating members’ own web pages. Participating members involved in undergraduate teaching, graduate student advisement, and extension activities at Land Grant Universities will disseminate knowledge developed from the proposed project activities in these respective forums. Project participants manage an established network of onsite wastewater training centers/programs where project information will be disseminated at local, regional and national stakeholder training workshops and classes that reach regulatory officials, professional engineers, land surveyors, environmental health specialist, soil scientists, registered sanitarians, OWTS installers, designers and maintenance service providers.

# Organization / Governance

A regional technical committee will be organized upon project approval. Operational procedures to be followed will be according to those outlined in the NIFA Manual for Cooperative Regional Research. The voting members of the regional technical committee will include one representative from each cooperating agricultural experiment station or institution appointed by the director. The administrative advisor and the NIFA representative will be considered nonvoting members. All voting members of the technical committee will be eligible for office. The offices of the regional technical committee will be the chair, vice-chair, and secretary and will serve as the executive committee. These officers for the first year will be elected at the organizational meeting for the technical committee. In subsequent years, the officers will be elected annually and may succeed themselves. The chair, in consultation with the executive committee, will appoint subcommittees to facilitate the accomplishment of the various research and administrative tasks involving the cooperating institutional representatives. Such tasks may include, but are not limited to, research planning and coordination, development of specific cooperative research procedures, assimilation and analysis of data from contributing scientists, and publication of regional bulletins. The duties of the technical committee will be to coordinate work activities related to the project. The chair, in accord with the administrative advisor, will notify the technical committee of the time and place of meetings, prepare meeting agendas, and preside at meetings of the technical committee and the executive committee. The chair is responsible for preparing the annual progress report and coordinating the preparation of regional reports. The vice-chair assists the chair in all functions. The secretary records the minutes and performs other duties assigned by the technical committee or the administrative advisor. Annual meetings will be held by the technical committee for the purpose of conducting business related to the project. During each annual technical committee meeting, the subcommittees will report on their progress and identified needs to the entire committee. Considerable time will be devoted to the discussion of these reports.

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# Attachments

N/A